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SECTION OF GEOLOGY AND MINERALOGY[1]

DECEMBER 2, 1940

DOCTOR M. KING HUBBERT, Geophysicist, New York, N. Y. *Motion of Ground Water.*[2] (This lecture was illustrated by lantern slides.)

The phenomena of geology are separated into two distinct domains by an opaque surface,—the surface of the ground. The facts of geology consist almost exclusively of visual observations made on the daylight side of that surface. The inferences of geology, on the contrary, concern largely the phenomena of the opaque and, hence, non-observable side. These inferences, therefore, consist, in the final analysis, of inventions of processes imagined to occur within the ground to account for our observations on the surface. We invent mechanisms inside the earth to account for mountains, volcanoes, and earthquakes observed upon its surface.

The motion of ground water, our subject for this evening,

[1] No meetings were held in December by the Sections of Psychology and Anthropology.

[2] This presentation is based upon a more comprehensive treatment contained in the following reference: M. King Hubbert. The Theory of Ground-Water. Jour. Geol. 48: 785–944. 1940.

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is peculiarly a problem of this kind. From its very definition, ground water is intrinsically non-observable. We, therefore, invent ground-water flow systems to account for our surface observations of wells, springs, and the like.

One of our main questions this evening is: How are we to know whether such an invention is a good one or a poor one?

Before answering this question let us propound another. The sciences of physics, chemistry, and astronomy—the so-called "quantitative sciences"—, as we all know, make extensive use of more or less exact relationships which have come to be dignified by the name, "laws." Do we in geology have any "laws" that we can employ to solve geological problems in general or the problems of ground water in particular? This is a question frequently discussed among geologists and usually leads to the somewhat apologetic suggestion that the "principle of superposition" in stratigraphy or the "doctrine of uniformitarianism" and other similar generalizations represent our nearest approach to "laws."

While many such generalizations are more or less true and reliable, I am going to suggest that they are all somewhat beside the point. They are vague and there is little one can do with them. On the other hand, I should like to point out that our phenomena in geology obey laws that are quite as rigorous and quite as valid as those of physics and chemistry. Furthermore, because I intend to use them repeatedly in the analysis of our problem of this evening, I should like to state two of the most fundamental of our laws in geology. I shall attempt to state them in a form that is peculiarly applicable as a criterion for determining the validity of our inventions.

These laws are:

I. Of all conceivable transformations that we may imagine to occur upon or within the earth, only those are to be regarded as possible for which the total mass of the matter involved is the same at the end of the process as at the beginning.

II. Of all conceivable transformations that we may imagine to occur upon or within the earth, only those are to be regarded

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as possible which are not equivalent to one or another kind of perpetual-motion mechanism.

All other transformations are impossible.

Applying these laws to flow mechanisms in ground water, we may now say that, of all conceivable flow systems which are in agreement with our observations, only those are to be regarded as possible, which do not involve the creation or the annihilation of water at one or more points of the flow-region, and which are not equivalent to one or another kind of perpetual-motion mechanism.

Deductions from the Principle of the Conservation of Matter

Although not strictly correct, it is an allowable approximation for present purposes to regard water, under the range of pressures encountered in wells, to be an incompressible fluid. Making this assumption, then it follows immediately from the first of our laws that, if we imagine any fixed, closed surface to be drawn in an underground region which is saturated with flowing water, the quantity of water flowing per unit of time into the volume inclosed by this surface is precisely equal to that flowing out in the same time interval.

If we specialize our closed surface, by choosing it in such a manner that it forms a tube or sleeve whose side walls coincide at every point with the flowlines of the water, then no fluid can cross its side walls. The fluid must enter or leave the tube across its end surfaces only. From the conservation principle, we are now able to say that, for any given stream-tube, if water flows in across one end, an equal amount must simultaneously flow out across the other, and also an equal amount must discharge across every cross section of the tube.

From this it follows immediately that, in the interior of any region of ground-water flow, no stream-tube can terminate. Instead, every such tube must either originate and terminate only upon permeable boundaries of the region, or else terminate by dispersion at great distances due to ever-increasing size of

cross sections and to the corresponding approach of the fluid velocity to zero.

In fact, for every stream-tube, the total discharge is given by

$$Q = qA = \text{constant}, \tag{1}$$

where Q is the total volume discharged per unit of time; q, the volume per unit of area normal to the flowlines per unit of time; and A, the cross-sectional area taken normal to the flowlines. From this, it is clear that the *specific volume discharge*, or velocity-vector, q, and the area of cross-section of the tube, A, are reciprocally related, and as one increases the other correspondingly decreases.

Since we can always choose a stream-tube such that any two non-contiguous streamlines occur at opposite ends of its diameter then it follows that, at points where the velocity is not zero, no two non-contiguous streamlines can ever coincide or intersect, for, in that case, we should have to close a stream-tube, which as we have already seen is not allowable.

Deductions from the Impossibility of Perpetual Motion

Let us now consider the question of the direction in which water must flow. The first thing that occurs to us is the familiar platitude that "water always flows down-hill." That this statement is of no validity is seen at once, if we consider the familiar example of the water-supply of a tall building obtained from a main buried underground. For, in this instance, unquestionably the flow of the water is up-hill.

We can best answer this question by returning to fundamentals. Let us take any point, P_0, as a datum, and from P_0 carry a unit mass of water along any path, A, to some other point, P_1. Let the work required to do this be w_{1A}. Next, return the unit mass of water to P_0 by a different path, B, with an expenditure of work, $-w_{1B}$. Now suppose that the work, w_{1A}, by the path A, is less than w_{1B} by the path B. In that case, we could carry water from P_0 to P_1, by the path, A, and obtain a net surplus of work, $w_{1A} - w_{1B}$, for each cycle. Then, if we connected the two

points by rubber tubes laid along the two paths, water would flow continuously. But this would be perpetual motion and, hence, impossible. Consequently, the work, w_{1A}, along the path, A, must be precisely equal to that of w_{1B} along the path, B, or the total amount of work required to carry a unit mass of water completely around any closed curve must be zero.

Exceptions to this occur in the cases of heat engines and in certain electromagnetic phenomena where other energy in addition to the work, w, is supplied. When this additional energy is taken into account, the contradiction vanishes. In ground water we may assume that we are not dealing with heat engines or electromagnetic phenomena, and so may regard the net work, w, required to carry unit mass of water around any closed curve, as our basic criterion for the existence or absence of a perpetual motion mechanism.

Since the amount of work, w, required to carry a unit mass of water from our datum point, P_0, to any point, P, is now seen to be unique and independent of the path, we can assign to P a unique value of a quantity, Φ, which we shall call the *hydraulic potential* at the point, P, and which is measurable by the amount of work, w, required to carry the unit mass from P_0 to P.

Thus

$$\Phi = \Phi_0 + w, \tag{2}$$

where Φ_0 is the datum value of the potential and can conveniently be set equal to zero.

Now, if we have two points, P_1 and P_2, whose potentials are Φ_1 and Φ_2, then $\Phi_1 = w_1$, which is the amount of work required to carry a unit mass of water from P_0 to P_1; and $\Phi_2 = w_2$, the work from P_0 to P_2. Now, suppose that $\Phi_2 > \Phi_1$. Then we could carry the unit mass from P_0 to P_2 by either of two paths: directly, or by way of P_1. In either case, however, the work must be w_2. By way of P_1, the work would be

$$w_2 = w_1 + (w_2 - w_1) \tag{3}$$

where w_1 is the work to P_1 and $w_2 - w_1$ the work from P_1 to P_2. Since, by hypothesis, $w_1 < w_2$, this positive work must be done

in going from P_1 to P_2, against an opposing force. Consequently, the fluid, if free to do so, would flow spontaneously from the point, P_2, having the higher potential, to P_1, having the lower. On the other hand if $\Phi_2 = \Phi_1$, the work required to go from P_1 to P_2 would be zero, and hence no driving force would be present.

We may say, therefore, that water always tends to flow from regions where the potential is higher to those where it is lower. Between points having the same potential, there is no tendency to flow. Conversely, if an unconstrained body of water remains motionless (static equilibrium), then the potential at all points within the body must be the same. Such a body comprises an equipotential region.

These relationships are valid regardless of the direction of the flow in space, whether up, down, or sidewise; or whether from regions of higher to lower, or from lower to higher fluid pressure.

The physical meaning of the potential, Φ, may become clearer by means of a concrete example. Consider a closed tank containing water and compressed air. Into the water let a pressure gauge and an open-topped manometer tube be tapped and terminated at a point, P, the value of whose potential we wish to determine. For our datum let

$$\left.\begin{aligned} z &= 0 \\ p &= p_0 \\ \Phi &= 0 \end{aligned}\right\} \tag{4}$$

be the elevation, pressure, and potential, respectively, where p_0 is the pressure of the prevailing atmosphere. Then at the point, P, we shall have a pressure, p, an elevation, z, and a potential Φ. The pressure, p, and the elevation, z, are known. Find the potential, Φ.

Remembering that Φ is the amount of work required to transfer unit mass of water from the datum state to the state at point, P, and that this is independent of the path, we may obtain the result in two different ways. We may lift the mass to the top of the manometer tube and then lower it along the tube to the point, P. The work done inside the liquid is zero, because this is

an equipotential region. The total work is then only that of lifting the mass to the elevation, h, of water in the manometer tube. The result is

$$\Phi = gh. \tag{5}$$

Alternatively, we may lift the mass to the elevation, z, of the point, P, and then inject it by a pump of some kind into the fluid chamber. The work by this path is

$$\begin{aligned} \Phi &= gz + (p - p_0)v \\ &= gz + \frac{p - p_0}{\rho}, \end{aligned} \tag{6}$$

where v is the volume of unit mass of fluid and $\rho = 1/v$, the density of the water. The work of injection is $(p - p_0)\, v$.

Combining equations (5) and (6), it follows that

$$\Phi = gh = gz + \frac{p - p_0}{\rho} \tag{7}$$

which enables us to measure the potential either by means of the manometer height, h, or the elevation, z, and the pressure, p, at the point, P.

The foregoing relationships are of quite general validity. In ground water, ordinarily a state of flow exists, so that we then do not have equipotential regions. Instead, there exists an infinite family of sub-parallel, equipotential surfaces arranged in a sequence of ascending or descending values of the potential. Let two successive surfaces have the potentials, Φ and $\Phi + \Delta\Phi$, respectively. Then the work required to carry a unit mass of water from any point upon the surface having the lower potential to any point upon that having the higher, by any path whatever, is $\Delta\Phi$. If we choose a rectilinear path of length Δs, then, since the work done is equal to the product of the opposing force by the distance, it follows that the average value of the opposing force must be

$$E_s = -\frac{\Delta\Phi}{\Delta s}, \tag{8}$$

where E_s is the component in the direction, s, of the force per unit mass, or *field intensity*, produced by the potential field. Since, in the case given, $\Delta\Phi$ is taken to be constant, then clearly the intensity, E_s, has its maximum value, E, when Δs is a minimum. This occurs when the path, Δs, coincides with the normal to the equipotential surfaces. Thus, at each point in the field, we have a driving force per unit of mass exerted upon the fluid at that point given by

$$\mathbf{E} = \lim_{\Delta n \to 0} -\frac{\Delta\Phi}{\Delta n} = -\text{ grad. } \Phi, \qquad (9)$$

where $\mathbf{E}$ is a vector whose magnitude is defined by equation (9), whose direction is perpendicular to the equipotential surface at that point, and whose sense is that of the direction of decrease of the potential.

For a constant value of $\Delta\Phi$ the intensity, $\mathbf{E}$, varies inversely as the distance, Δn, of separation of the two equipotential surfaces becoming infinite as Δn tends to zero. Since infinite values of $\mathbf{E}$ are precluded by physical considerations, then it follows that Δn cannot be reduced to zero. Consequently, no two different equipotential surfaces can ever intersect or coincide.

Associated with the aforementioned infinite family of equipotential surfaces is, therefore, a field of force whose lines at every point are tangential to the intensity vector, $\mathbf{E}$, and everywhere orthogonal to the equipotential surfaces.

Relation between the Field of Flow and the Potential Field

Heretofore, we have dealt with the flow field and the potential field as if they were unrelated. Since, in a permeable skeletal solid, such as a sand, the fluid is free to move, the field of force will act upon it and produce a fluid movement in a generally down-gradient direction. What we wish to know is the precise relation between the rate of fluid flow and the field intensity, $\mathbf{E}$, at any given point. While this can be deduced theoretically from basic physical relationships (except for a dimensionless

factor depending upon the internal shape of the sand), it is simpler for present purposes to appeal to experiment. For this purpose, all that is required is a sample of the given sand through which the water is made to flow rectilinearly. Measurement of the volume discharge and the area of cross-section gives the flow vector, **q**. Measurement of the potential at two points and the distance between them parallel to the flow gives the potential gradient and hence **E**.

Experiments of this sort give for isotropic media the result:

$$q = -\sigma \text{ grad. } \Phi = \sigma \mathbf{E}, \tag{10}$$

where σ is a proportionality fact or whose value depends both upon the nature of the sand and the viscosity and density of the water. We shall refer to σ as the *specific fluid conductivity*. Since equation (10) is a vector equation, it tells us that at each point the direction of flow is the same as the direction of the field intensity, **E**, and proportional to **E**. Consequently, the flowlines form an orthogonal system with the equipotential surfaces and coincide with the lines of force.

In anisotropic media the conductivity, σ, varies with the direction of flow. In this case, in general, the lines of flow are somewhat oblique to the lines of force. While it is known that many sediments are somewhat anisotropic, in what follows we shall assume the rocks dealt with to be isotropic only.

The relationship of equation (10) was established empirically in 1856 by a French engineer, Henry Darcy, who studied the flow of water through filter sands. It is valid only for velocities sufficiently small that the forces due to inertia are negligible compared with those due to viscosity, which, for water in coarse sand, corresponds to velocities of the order of 1 cm./sec., or less. In ground-water flow rarely are the velocities this great.

Boundary Conditions

We are now able to consider the conditions of flow across any kind of a boundary to the flow field. For such a boundary, consider a plane surface separating one region from another, or

dividing the same region into two parts. Across this boundary, our two basic laws must hold: The quantity of fluid leaving one region must be equal to that entering the other. There must not be perpetual motion. The first of these conditions requires that the component of flow normal to the boundary in the first region must be equal to that in the second.

$$q_{n1} = q_{n2}. \tag{11}$$

The second condition is obtained if we carry a unit mass of water around a rectangular closed path whose long sides are parallel to the boundary, one in each of the regions respectively. The work around this path must be zero. Hence, since the length of the two sides parallel to the boundary is the same, the work done along one must be equal and opposite to that along the other and the component of the potential gradient parallel to the boundary must be the same on both sides.

$$\left(\frac{\partial \Phi}{\partial s}\right)_1 = \left(\frac{\partial \Phi}{\partial s}\right)_2 \text{ or } (E_s)_1 = (E_s)_2, \tag{12}$$

where s is a length along the boundary.

The conditions imposed by equations (11) and (12) determine fundamentally the fluid behavior at or across all boundaries. If, for example, one side of the boundary is an open basin filled with water at sensibly constant potential, and the other side is a sand of uniform permeability, the tangential component of the potential gradient must be zero. Hence, the lines of force and of flow must enter or leave the side walls of the basin perpendicularly. At the same time, the equipotential surfaces in the sand must be parallel to the side walls of the basin.

The opposite of this effect is encountered at a boundary between a region of finite and one of zero conductivity. In this case, the normal component of flow must be zero, so that the total flow must be tangential to an impermeable boundary, and the equipotential surfaces must terminate upon such a boundary perpendicularly.

For a more general case, consider the flow across a boundary between two regions of finite conductivities, σ_1 and σ_2. In this case, for the normal components of flow we have

$$-\sigma_1 (\text{grad } \Phi)_1 \cos \theta_1 = -\sigma_2 (\text{grad } \Phi)_2 \cos \theta_2, \tag{13}$$

where θ^1 and θ^2 are the angles the flowlines make with the normals in the first and second regions respectively.

For the tangential components of the potential

$$(\text{grad } \Phi)_1 \sin \theta_1 = (\text{grad } \Phi)_2 \sin \theta_2. \tag{14}$$

Solving equations (13) and (14) for $(\text{grad } \Phi)_1/(\text{grad } \Phi)_2$ and equating them, gives

$$\frac{\sin \theta_1}{\cos \theta_1} \frac{\cos \theta_2}{\sin \theta_2} = \frac{\tan \theta_1}{\tan \theta_2} = \frac{\sigma_1}{\sigma_2}. \tag{15}$$

Hence, in such an instance, the flowlines refract in a manner resembling light except that the flow refracts according to a tangent law, whereas the refraction of light follows a sine law.

In the case of a flowing body of fresh water in contact with a static body of denser salt water, the salt water acts as an impermeable boundary aside from diffusion. Hence, the fresh-water flowlines are tangential to this boundary and, in the fresh-water region, the equipotential surfaces approach the boundary perpendicularly. In the salt-water region, the fresh-water equipotential surfaces are horizontal with equidifferent surfaces equally spaced, the potential increasing with depth. Unlike previous boundaries, however, the present one is adjustable, and, in fact, it must at all times assume such a position and attitude that the two families of fresh-water equipotential surfaces, in the separate regions, must connect at the interface.

The greater the velocity of the fresh water, the closer the spacing of the equipotential surfaces in that region. Hence, in order to maintain connections with the corresponding fixed system of fresh-water equipotential surfaces in the salt-water region, the interface must tilt upward in the direction of the flow, the angle of slope increasing continuously with the rate of flow

of the fresh water. For static fresh water, the interface becomes horizontal.

At the fresh-water-air interface the same kind of thing is true, except that the interface must tilt downward in the direction of the flow.

An especially interesting problem is presented by the zone of stagnant fresh water frequently described in the geology textbooks as lying beneath a superficial zone of flow. Let us consider the boundary between these two zones. To this interface the flowlines in the flowing zone must be tangential and upon it the equipotential surfaces from the flowing zone must terminate orthogonally. The stagnant region must be an equipotential region.

Now, let us carry a unit mass of water around a closed path extending across the interface. Let us begin at a point of potential Φ_1, in the flowing region, and follow that equipotential surface to the stagnant region; thence, through that to a point opposite to the equipotential surface, Φ_2. We then traverse this surface into the flowing region, and finally return down-gradient to the initial point. All of this traverse requires zero work except the last link. In going directly from Φ_2 to Φ_1 in the flowing region, we obtain the work, $\Phi_2 - \Phi_1$, which is the net work for the whole traverse and is not zero. This is clearly equivalent, therefore, to a perpetual motion mechanism and, hence, impossible.

Consequently, we must conclude that the familiar conception of a flowing zone of water overlying a static zone, which is not physically different, is a fiction. Also, we learn that no equipotential surface can terminate in the interior of a region of flow. It must extend to a boundary.

Furthermore, the potential inside a region of flow cannot have either maxima or minima, for, in that case, we should have regions about which the equipotential surfaces would close completely upon themselves, giving closed regions over whose boundaries the flow is either entirely inward or entirely outward; either instance violates the conservation principle.

Uniqueness Theorem

This latter fact enables us to deduce immediately what is perhaps the most important theorem of the entire subject. This pertains to the following question: Suppose we are given an underground region bounded by one or more completely closed surfaces. Let the specific conductivity at each point inside this region be given, and the potential at each point of those parts of the bounding surfaces which are permeable to flow. Can there be a multiplicity of different potential fields and flow fields within the bounded region satisfying the conditions given, or is there only one? In other words, is the solution of the problem unique?

To answer this question, we assume that there are two potential fields which satisfy all the conditions given. Let these be respectively Φ' and Φ''. Corresponding to these two potential fields, there must also be two flow fields, $\mathbf{q}'$ and $\mathbf{q}''$. Now, any potential field may be thought of as the algebraic sum of any number of component fields:

$$\Phi = \Phi_1 + \Phi_2 + \ldots . + \Phi_n. \tag{16}$$

Similarly, any flow field may be regarded to be the geometrical sum of any number of component flow fields:

$$\mathbf{q} = \mathbf{q}_1 + \mathbf{q}_2 + \ldots . + \mathbf{q}_n. \tag{17}$$

Consequently, for the two supposed fields, Φ' and Φ'', we may think of Φ'' as being the sum

$$\Phi'' = \Phi' + \Phi''' \tag{18}$$

and

$$\mathbf{q}'' = \mathbf{q}' + \mathbf{q}''', \tag{19}$$

where Φ''' and $\mathbf{q}'''$ are the differences between the two supposed potential and flow fields, respectively. Also, $\mathbf{q}'''$ must be related to Φ''' in the usual manner:

$$q''' = -\sigma \operatorname{grad} \Phi'''. \tag{20}$$

At all permeable boundaries, however, since the potentials are there specified, the two potentials must be the same, and their

difference, Φ''', equal to zero. Then, if the field, Φ''', is not zero at all points in the interior, it must have one or more maxima or minima. About these the surfaces, $\Phi''' =$ constant, must close completely, giving regions across whose boundaries the flow field, $\mathfrak{q}'''$, is entirely inward or outward. But this, from the conservation principle, is impossible.

Therefore, at all points in the interior of the flow region,

$$\left.\begin{aligned} \Phi''' &= 0 \\ \mathfrak{q}''' &= 0 \\ \Phi' &= \Phi'' \\ \mathfrak{q}' &= \mathfrak{q}'', \end{aligned}\right\} \tag{21}$$

and there is one and only one possible field of flow corresponding to the conditions given.

The same conclusion may be drawn by somewhat similar reasoning, if, instead of the potentials over the permeable boundaries of the flow field, we are given the normal components of the flow vector at all points.

Hence, within any underground region for which the specific conductivities at all points are supposed to be known, and for which either the flow field or the potential field over all external permeable boundaries is given, out of all conceivable types of flow which one might imagine to occur, there is one and only one which is possible. All the rest involve either the creation or annihilation of matter; or are equivalent to a perpetual-motion mechanism, and, hence, are impossible.

Only in the simplest cases, can the possible solution be obtained by mathematical analysis. In more complex cases, exact solutions are best obtainable by suitable models, either fluid or electrical. Approximations quite accurate enough for most purposes, however, are readily obtainable graphically, by the proper observance of the various restrictions set forth in the present discussion.

Conclusions

In closing, it seems appropriate to direct our attention once more to what have here been called the fundamental laws of

geology. The first of these has no doubt been recognized as the familiar Principle of the Conservation of Matter. The second, however, may not have been recognized as embracing the less familiar First and Second Laws of Thermodynamics.

Although the science of geology is, by definition, "the science of the earth," of which the atmosphere, the hydrosphere, and lithosphere are taken to be the principal divisions, what has come to be called "geology" is a certain conventionalized mode of behavior with respect to the earth, consisting principally of the sequence: observation, description, and geometrical and kinematical interpretation, plus no inconsiderable amount of unbridled speculation.

The weak member of this series is that of interpretation, for it consists largely of the invention of mechanisms supposed to operate on the non-observable side of that opaque surface—the outer boundary of the lithosphere; or, in the equally non-observable geologic past, without the employment of adequate criteria, to enable one to determine what supposed mechanisms are physically possible.

Prominent among such criteria are the laws we have stated and demonstrated.

In this connection, it is significant to note that ground water is one of the oldest of geological subjects. It has been the object of more than 300 years of investigation by naturalistic methods. Yet, despite this fact, we, here, this evening, have been able to deduce from our two basic laws a greater number of reliable relationships governing the flow of water underground than have been produced in that entire 300 years by naturalistic methods—most of them, in fact, never discovered by such methods. More convincing evidence of the importance of these laws need hardly be cited.

As a matter of fact, the application of these laws to terrestrial phenomena is not new. The methods that we have here demonstrated with respect to ground water have long since become standard when dealing with the atmosphere and the oceans. As long ago as the decade between 1900 and 1910, the Norwegian

hydrodynamic engineer, V. Bjerknes, by the employment of the same basic relationships, established the principles and methods of dynamic meteorology and oceanography which have subsequently become standard the world over, completely supplanting from those domains the naturalistic method.

Adding to this earlier work our interrogations of this evening, along with the contemporary progress being made in other branches of general hydrology, we are led inescapably to the conclusion that, of the triumvirate of domains originally embraced by naturalistic geology, only the lithosphere now remains.

While the dynamic transformations of the lithosphere are, without question, of much greater complexity than those of the atmosphere and the hydrosphere, this fact in nowise invalidates the employment in that domain of the methods (with appropriate modifications) that have already been applied with complete success to the atmosphere and the hydrosphere. In fact, the very difficulty of the problems of the lithosphere renders the use of such methods imperative. Furthermore, as indicated by the investigations of the Geophysical Laboratory, the seismologists, and others, such work is already well begun.

In the early stages of the evolution of a science of the earth, the naturalistic method was not only the appropriate, but also the necessary one. With the advance of time, however, it has become increasingly inadequate as a means of dealing with the newer problems that have arisen, until, at last, its almost exclusive employment as the only legitimate method in geology is beginning to amount to a positive impediment to progress. Yet, despite this fact, a continuous transition to the more advanced dynamical method of treatment—made largely at the hands of non-"geologists"—has been in progress since the beginning of the present century. There is every reason to expect that this advance will continue, and that, in the comparatively near future, we shall achieve a unified body of dynamical theory which embraces, not only the gaseous and the liquid portions of the earth, but the solid portion also.

It is to be hoped, therefore, that the studies of the separate

members of our terrestrial family—the atmosphere, the hydrosphere, and the lithosphere—having passed their periods of adolescence, may again be soon united. When that day arrives, Geology will indeed become, what it has never been before—the proud Science of the Earth, with apologies to no man!

SECTION OF BIOLOGY

DECEMBER 9, 1940

DOCTOR C. O'D. ISELIN, Director, Woods Hole Oceanographic Institute: *The Biological Significance of Some Recent Developments in Physical Oceanography.* (This lecture was illustrated by lantern slides.)

Three recent investigations at the Woods Hole Oceanographic Institution illustrate the desirability of close collaboration between physical and biological oceanographers.

1) It has often been suggested that the marked variations in the stock of such fish as the haddock largely depend on survival during the first few weeks after spawning. An intensive study of the biological factors influencing the young haddock on Georges Banks has been in progress for more than a year, but from the standpoint of physical oceanography only a large scale physical phenomenon seems likely to be sufficiently variable to account for the great fluctuations in the numbers of haddock able to reach the bottom-living stage. The great eddies which form between the Gulf Stream and the edge of the continental shelf during periods of weakening flow perhaps explain the occasional very poor year class, for these eddies apparently cause large volumes of bank water to move offshore and to mix with water from the Gulf Stream.

2) A new study of the convectional pattern of flow in the surface layer of the ocean and in the lower layer of the atmosphere was suggested recently from biological evidence. The streaks of gulfweed which are sometimes observed in the North Atlantic indicate alternating bands of convergence and divergence at the surface during periods when instability prevails. In the same manner observations by Woodcock on the flight of herring gulls show a similar pattern of flow in the lower layer of the atmosphere when the air is colder than the water and when the winds are stronger than a certain critical value.

3) A cheap, reliable submarine camera, developed by Ewing to photograph a current indicator placed on the bottom, has provided a new biological instrument. This camera is able to secure clear pictures of the sedentary bottom population at depths as great as 100 fathoms. A hundred or more photographs taken last spring on Georges Banks each give an accurate census of about 6 square feet of the bottom.

REPORT OF THE ANNUAL MEETING

DECEMBER 11, 1940

The 123rd[1] Annual Meeting of the Academy for the election of Officers and Fellows, the presentation of reports and the transaction of other business was held at The Hotel Astor on the evening of Wednesday, December 11.

The Corresponding Secretary reported that there are now upon the rolls of the Academy 46 Honorary Members and 6 Corresponding Members. Two deaths were reported during the past year.

The Recording Secretary reported another year of widely increased activities and progress. During 1940, the Academy held 8 Business Meetings and 25 regular Sectional Meetings, at which 25 stated papers were presented. Five informal receptions were held under the auspices of the various Sections of the Academy in honor of prominent speakers.

The Section of Physics and Chemistry held three conferences on special subjects of research under the following titles: "Physical, Physical-Chemical and Organic-Chemical Evidence Regarding Crystalline Protein Molecules," "The Primary Process in Photochemistry," and the "Amphoteric Properties of Proteins."

The Recording Secretary again thanks the Members of the Academy for their continued and increasingly active support of the undertakings of the past year. This is evidenced, not by their greatly increased demand for the publications of the Academy, but also by the impressive fact that more than 3,000 persons attended the meetings during the above period.

One Honorary Member, 3 Life Members, 9 Sustaining Members, 241 Active Members, 213 Associate Members, and 11 Student Members were added to the rolls. Thus a total of 478 new members were added during the year.

[1] In the report of the Annual Meeting for December 13, 1939, the meeting was erroneously referred to as the "121st Annual Meeting of the Academy." It was actually the 122nd Annual Meeting.

The present membership of the Academy is 1590, which includes 1 Patron, 100 Life Members, 153 Sustaining Members, 698 Annual Active Members, 531 Associate Members, 54 Student Members, 47 Honorary Members and 6 Corresponding Members. Of these 224 are Fellows.

The Editor reported that since the last Annual Meeting of the Academy, five parts of the Annals were published and, in addition, one is being printed and will appear December 20th; one is in page proof, and one is in galley form. Two of the latter will be published before the end of the calendar year.

A list of these is as follows:—

"American Cities and States: Variation and Correlation in Institutions, Activities and the Personal Qualities of the Residents," by Edward L. Thorndike, pp. 213–298.

"Kinetics in Solution," by Frank Brescia, Henry Eyring, Keith J. Laidler, Victor K. LaMer, Samuel H. Maron, Irving Roberts, George Scatchard, J. C. Warner, and F. H. Westheimer, pp. 299–408.

The above two parts complete Volume XXXIX. The following parts are included in Volume XL.

"Studies on the Nutrition of Colorless Euglenoid Flagellates. 1. Utilization of Inorganic Nitrogen by Astasia in Pure Cultures," by Henry W. Schoenborn, pp. 1–36.

"Free Radicals as Intermediate Steps in the Oxidation of Organic Compounds," by L. Farkas, Manuel H. Gorin, L. Michaelis, Otto H. Muller, Maxwell Schubert, and G. W. Wheland, pp. 37–266.

The parts now in press are as follows:

"Recurrent Paleozoic Continental Facies in Pennsylvania," by Bradford Willard, pp. 267–288.

"Dielectrics," by William O. Baker, J. D. Ferry, Raymond M. Fuoss, Paul M. Gross, Marcus E. Hobbs, John G. Kirkwood, S. O. Morgan, Hans Mueller, J. L. Oncley, Herbert A. Pohl, J. Shack, Charles P. Smyth, J. H. VanVleck.

"The Internal Constitution of the Stars," by Zdenek Kopal, Robert E. Marshak, Henry Norris Russell, Harlow Shapley, Jaakko Tuominen.

Title page for volume XXXIX.

The parts of the Scientific Survey of Porto Rico and the Virgin Islands that have appeared, and those now in press are as follows.

Volume XVIII, Part 1, "Porto Rican Archaeology," by Froelich G. Rainey, pp. 1–208.

Volume XII, Part 2, "Insects of Porto Rico and the Virgin Islands, Moths of the Family Noctuidae," by William Schaus, pp. 177–290.

Volume XII, Part 3, "Insects of Porto Rico and the Virgin Islands, Moths of the Families Geometridae and Pyralididae," by William Schaus, pages 291–417.

Volume XVI, Part 3, "Bryozoa of Porto Rico," by Raymond C. Osburn.

Volume XVIII, Part 2, "Archaeological Sites, etc." by J. Alden Mason.

Transactions, Series II, Volume 2, together with the title page and table of contents, constituting a 229 page volume was printed and distributed.

The total number of pages printed to date since the first of the year in the Annals, Scientific Survey of Porto Rico and the Virgin Islands, and the Transactions, combined, is 1140.

The Librarian reported that 15,102 separate publications were distributed to the members of the Academy, authors, exchanges and the sales list, classified as follows: *Annals*, 7,169; "Scientific Survey of Porto Rico and the Virgin Islands," 922; *Special Publications*, Volume I, "Climate and Evolution," 215; TRANSACTIONS, Series II, Volume II, 6,674; and "Man in a Chemical World," 122.

The Library of the Academy has received 1,709 publications from its exchange institutions.

The Treasurer reported that the surplus for the fiscal year ending November 30, 1939, was $9,173.75. During the past year ending November 30, 1940, receipts from all sources amounted to $19,819.72, making a total, with the amount transferred above, of $29,093.47. The disbursements for the past year amounted to $19,572.84, leaving a balance of $9,520.63.

A new fund to be known as the George Herbert Sherwood Memorial Fund, with a capital of $7,000, was set up early in the year, out of the surplus of the preceding year, thus reducing it to $2,520.63.

During the year, there was a shrinkage from the book value of the Academy's capital funds, due to the sale of non-income producing securities, amounting to $8,388.21, but, by reinvestment, the total annual income of the invested funds gained $1,430.20 over the income of 1939. Subtracting the surplus, the net shrinkage amounted to $5,967.58.

The balance sheet shows assets of cash in bank, $7,334.50, and investments in mortgages, real estate and corporation stocks and bonds of $90,136.84, making a total of $97,471.34.

The A. Cressy Morrison Prizes of $200.00 each for the two most acceptable technical papers in a field of science covered by the Academy or an Affiliated Society were awarded to the following papers entitled:

"Systematic Revision of the Silurian and Devonian Terebratuloid Brachiopoda" by Preston E. Cloud of Missouri School of Mines and Metallurgy, Rolla, Missouri.

"The Aortic Arch in Primates" by C. F. DeGaris of the University of Oklahoma, School of Medicine, Oklahoma City, Oklahoma.

The Astronomical Prize (1), namely that of $500.00 for the best paper on the origin of solar and stellar energy, was awarded to the paper entitled:

"The Sources of Stellar Energy," by Robert E. Marshak of the University of Rochester and H. A. Bethe of Cornell University.

The Committee takes great pleasure in congratulating the authors of these papers upon their splendid treatment of their subjects and the fundamental importance of their results.

Announcement was made that Mr. Morrison has generously renewed the offer of the two prizes of $200.00 each for the coming year, the awards to be made at the Annual meeting, which will be held in December, 1941. These prizes, again, are offered for

the two most acceptable papers in natural science, within the scope of the various sections of the Academy and the Affiliated Societies, to members in good standing at the time that the papers are submitted. The precise terms of the competition will be published in a later issue of the TRANSACTIONS and will be distributed to all members of the Academy and Affiliated Societies.

The following members were elected to Fellowship:

Frank A. Beach, Ph.D.
Alan A. Boyden, Ph.D.
Trigant Burrow, M.D., Ph.D.
R. Keith Canan, Sc.D.
George Henshaw Childs, Ph.D.
Hans T. Clarke, Sc.D.
Edwin J. Cohn, Ph.D.
Edwin H. Colbert, Ph.D.
Edward Spencer Cowles, M.D.
J. A. Dawson, Ph.D.
Vincent du Vigneaud, Ph.D.
John C. Flanagan, Ph.D.
Magnus I. Gregersen, Ph.D.
Alfred Gundersen, Dr. de l'Univ., Paris
Michael Heidelberger, Ph.D.
Leonor Michaelis, M.D.
Frederick K. Morris, Ph.D.
William West, Ph.D.

Honorary Membership was conferred upon the eminent anthropologist, Sir Arthur Keith, M.D., LL.D., D.Sc., F.R.S., F.R.C.S.

The following officers were elected:

President
Roy Waldo Miner

Vice-Presidents
Leslie E. Spock
John C. Flanagan
Charles M. Breder, Jr.
Ralph Linton
Victor K. LaMer

Recording Secretary
Duncan A. MacInnes

Corresponding Secretary
C. Stuart Gager

Treasurer
Marvin D. Thorn

Librarian
Barnum Brown

Editor
Erich M. Schlaikjer

Councilors (1941–1944)

John Hendley Barnhart Frank A. Beach

Finance Committee

Herbert F. Schwarz Wayne M. Faunce

Wyllys Rossiter Betts, Jr.

The program of the Annual Dinner and Meeting was an innovation on the procedure of previous years.

Through the courtesy of the Walt Disney Productions, the Members of the Academy and Affiliated Societies had the exceptional opportunity of witnessing that portion of Walt Disney's FANTASIA which has for its theme the origin and evolution of the world, the appearance of life in the seas, the invasion of the continents by the first amphibians, and the evolution and dominance of the great dinosaur reptiles. It closed with the last phases of the Cretaceous Period and the decadence and death of these prehistoric monsters. It is set to the music of Stravinsky's "Rite of Spring" as interpreted by Leopold Stokowski and the Philadelphia Symphony Orchestra, by means of an unusual method of sound-reproduction.

This episode of FANTASIA was accomplished with the cooperation of the Mount Wilson Observatory, paleontologists of the California Institute of Technology, the University of California, and especially of Doctor Barnum Brown, our fellow member and Curator of Fossil Reptiles at the American Museum of Natural History. It was presented as a fine demonstration of what can be accomplished when the highest technique of motion picture animation joins forces with science in displaying the romantic and striking side of scientific research.

After the Business Meeting, the following program was presented:[1]

[1] Due to unavoidable circumstances, Professor Edwin Grant Conklin was unable to be present to give his paper on "Biological Bases of Democracy" as had been previously announced.

"The Methods of Walt Disney Productions"

Demonstrated by

BARNUM BROWN

"Around the War to Syria and Lebanon"

by

HAROLD E. VOKES

Abstracts of these papers, and also those of the A. Cressy Morrison prize winners, are included in this issue of the TRANSACTIONS.

THE NEW YORK ACADEMY OF SCIENCES

Address given at Annual Dinner and Meeting

DECEMBER 11, 1940

DOCTOR BARNUM BROWN, The American Museum of Natural History, New York, N. Y.: *The Methods of Walt Disney Productions.*

Doctor Brown is eminent as an authority on dinosaurs. He gave a short account of his collaboration with Walt Disney in the production of the part of FANTASIA relating to dinosaurs and described the results of his recent expedition to the dinosaur beds of Texas. This lecture was illustrated by slides, drawings and motion pictures.

An extended abstract of this paper will be printed in the February issue of TRANSACTIONS.

THE NEW YORK ACADEMY OF SCIENCES

Address given at Annual Dinner and Meeting

DECEMBER 11, 1940

DOCTOR HAROLD E. VOKES, The American Museum of Natural History, New York, N. Y.: *Around the War to Syria and Lebanon.* (This lecture was illustrated by lantern slides and motion pictures.)

Early in 1939, President Bayard Dodge of the American University of Beirut outlined a project calling for an investigation of the stratigraphy and invertebrate paleontology of the Lebanon Mountains in Syria. He suggested that this be considered as a cooperative study, whereby I, as the representative of The American Museum of Natural History, undertake the study with the university aiding in the field and contributing the great collection of fossils amassed by the late Rev. William Bird and Professor Day. This was approved by the Museum authorities and I was authorized to undertake the study.

Financial problems were solved early this spring by the award of a fellowship grant by the John Simon Guggenheim Memorial Foundation and I was able to leave for the field in April.

The Lebanon Mountains are at the eastern end of the Mediterranean Sea in the "Republic" of Lebanon, one of the small units of the French mandate of Syria. At the time of my sailing, France was at war with Germany, and Italy was threatening to enter at any moment. It was obvious that I might have some interesting, and possibly tense, moments, but President Dodge had written that the presence of General Weygand and a large French army had so impressed the Arabs that it was safer to do field work in the mountains than it had been for some years.

Two days out of New York, we had our first contact with the war when our ship was accosted by a British cruiser which

inquired into our nationality, destination, cargo, etc. At Punta Delgado, in the Azores Islands, we saw two German and one Danish tanker, which had lain at anchor in these neutral (Portuguese) waters since their respective countries had entered the war. Some thirteen hours were spent in the harbor at Gibraltar for contraband control. Navicerts for the cargo were examined and all mail consigned to Germany was removed for censorship. Later, as we left the harbor, we watched a convoy of fifty-eight armed tankers and freighters forming off the "Rock" for the dash through the Atlantic waters to England.

We reached Genoa on the tenth of May, the day when the Germans (to quote the Italian newspaper headlines) "assumed the protection of Holland, Belgium and Luxemburg." At that time Italy was threatening to enter the war, and, at the same time, protesting that she did not wish to take this step, but was being forced to do so because of the "arrogant attitude" of the democracies who were "refusing Italy that which was rightfully due her." At the quay where we were docked, the large freighter "Umberto" and the larger freight-passenger "Colombo" were both busily engaged in loading artillery, shells, rifles, machine guns, cartridges, and chemicals . . . all consigned to Massawa in Eritrea. It seemed obvious that Italy's future policy was already determined and that she was waiting only until her colonies, especially those in East Africa, were fully equipped, before making her declaration.

The bay at Naples was crowded with Italian naval units—submarines, destroyers, cruisers, an air-craft carrier, and, more significantly, many troopships; and some were already being painted as Red Cross hospital ships.

Three days later, we cautiously passed through the minefield and into the harbor at Alexandria, crowded with British and French naval units, the Allies' answer to the Italian threats. Alexandria was under martial law and here we had our first blackout, an experience which we were to have every night for most of the next three months.

On the morning of May twenty-first, we reached Beirut,

though we had to stay off shore for about four hours, while the coast defense forces engaged in artillery practice. Even as I landed and went through customs, I began to realize the important place that the American University held in this region and the extreme good-will which has been generated by the administration of President Dodge. He has been described as the most influential American in the near East and is one of the few civilian Americans to have been made a member of the Legion of Honor. Despite the necessary formalities, made more strict by war conditions, the information that I was bound for the University resulted in an amazing degree of cooperation from all concerned.

The University is one of the most cosmopolitan organizations that it has ever been my privilege to visit. During the academic year 1939–1940, it had an enrollment of 1850 students in the various schools. These came from some forty countries. The greater number were from Syria and Lebanon, Palestine, Iraq and Egypt; but other countries represented, included Iran, Hedjaz, Transjordan, Turkey, Sudan, Zanzibar, Straits Settlements, India, Japan, Tunis, Greece, Switzerland, Poland, France, England, Brazil, Panama, Guatemala, Chile, Mexico and the United States. The faculty is almost equally cosmopolitan in composition. Fourteen nationalities and eleven religious sects (counting all Protestant denominations as one) are represented.

I arrived on the campus to find it very war conscious. The academic year had begun on the day that Germany had invaded Poland. When France had declared war, sixteen members of the faculty had been mobilized into her army. Now the imminent entry of Italy was threatening to bring the war even closer. Beirut was a French naval base. The entrance to the harbor was mined and all ships had to be guided through the mine-field and past the submarine nets into the port. Trenches were constructed on the campus to serve the dual purpose of air-raid shelters and coast defense in the event of any attempted invasion. Barbed wire entanglements stretched the entire length of the coast-line. The University swimming facilities had been transformed into a machine-gun post manned by very black Senegalese soldiers.

In fact, soldiers were everywhere. France had an army of about 500,000 men in the mandate. The troops were mainly from the French colonies and consisted of natives officered by Europeans. There was also a considerable detachment of the famed Foreign Legion and some 6,000 Polish soldiers. After the collapse of France, the Poles and a considerable number of the Foreign Legionnaires crossed into Palestine and joined the British army there.

Despite all the war hysteria, all the soldiers quartered among them, and all the army trucks and equipment which rumbled through their villages, the life of the country people seemed but little affected. They continued to live as their ancestors had, so that it almost seemed as if they were wholly unaware of the actual fact of war. The sparse crops were being reaped by hand; threshed by oxen on a flat, sun-baked clay threshing floor; and winnowed by being tossed into the air with a fork made of a pronged stick. Water was drawn from the village well in pottery jars and carried home on the heads of the women, though the more serviceable, and less picturesque, five-gallon oil tin is not an uncommon sight. The itinerant merchant, with his wares piled high on an over-burdened donkey, still vied with the shepherds and their fat-tailed sheep, as traffic hazards for the motor car.

For three months, I traveled back and forth across the southern and central parts of the Lebanon mountains studying the geology and amassing a large collection of fossils. Italy entered the war early in June and the last American ship left Beirut shortly afterward. I was fortunate to be able to get one box of fossils on board, but the rest had to remain in Beirut when I left, and probably will not be forwarded until the end of hostilities frees the Mediterranean for normal shipping movements.

Although Tertiary rocks (Eocene, Miocene and Pliocene) occur on the flanks, the Lebanon Mountains themselves are composed of Jurassic and Cretaceous deposits. The oldest Jurassic strata are 1,500 feet of rather heavy-bedded bluish-gray limestones with a thin zone of ash and basalt, and a thinner brecciated and nodular, bluish limestone zone at the top. The greatest

observed thickness of the ash and basalts was slightly less than 30 feet. In general, fossils are too poorly preserved for determination, but two well-preserved pelecypods found in the upper nodular zone are identical with specimens from the Kimmeridgian deposits of Ethiopia, and indicate that these upper beds, at least, are of that age.

Apparently, conformably overlying these limestones is a thin series of sandy, yellow limestones and clays with oolitic limestones above. Fossils are common in a number of localities. The fauna, however, is not large, the collections containing abundant representatives of a few species. The most characteristic element is the large spines of *Balanocidaris glandarius*. This fauna is tentatively considered to be of Portlandian age.

There is a pronounced unconformity between the Jurassic and the Cretaceous deposits, and the erosion which occurred during this period resulted in the development of deep channels, which penetrate well down into the Kimmeridgian limestone in many places, and result in a very discontinuous distribution of the Portlandian (?) strata. The continental red sandstones and shales of the earliest Cretaceous deposits are in marked contrast with the more drab colors of the Jurassic strata and serve to emphasize the physical features of the break. These Cretaceous beds are tentatively referred to the Neocomian and, in a broad sense, may be correlated with the Nubian sandstone. The sandstones are coarse and arkosic and contain abundant iron concretions which have been used in the past as a source of iron ore. The shales are often red or variegated in color, some of the darker ones containing thin seams of lignite. Basalt flows are fairly extensively developed in the lower part of the section and, in some areas, additional flows occur at the very top of the formation. The most common fossils are casts of the stems and trunks of fossil trees. None were seen which exhibited any evidence of their original woody structures. Isolated dinosaur vertebrae have been found as well as the head of the femur of a large sauropod resembling *Diplodocus*.

Marine deposition returned with the beginning of Aptian

time. The deposits of this epoch appear to be everywhere conformable with those of the Neocomian, and the age determination of the continental beds is primarily based upon their apparent relationship with these Aptian strata. Deposition may have been almost continuous in this area. The lower Aptian beds are coarse gray to buff sandstones which rapidly grade up through finer sandstones and some minor gray shales to buff and gray limestones,—some oolitic, with gray shale partings. These lower Aptian deposits are abundantly fossiliferous with a molluscan fauna, predominantly gastropods and pelecypods. Echinoids are not rare, the most diagnostic species being *Heteraster oblongus* var. *syriacus*.

Above this lower zone, there is a wide-spread horizon composed of massive blue-gray limestones. These limestones are resistant and stand out as prominent cliffs throughout much of the Lebanon area. The maximum observed thickness is about 175 feet, the average being nearer 160 feet. It is one of the most wide-spread guide horizons for geological studies in this region. Dubertret has suggested the name "Failles de blanche" for this zone.

About one hundred feet of upper Aptian deposits occur above the cliff limestones. A thin zone of purplish volcanic ash is characteristically present at the base. Above are sandstones, sandy shales, dolomitic limestones and limestones containing abundant fossils. A zone of *Orbitolina conoidea-discoidea* and one of *Radiolites plicatus* are normally to be found in the lower beds of this horizon. Above, is a zone containing abundant casts of large pelecypods. *Heteraster oblongus syriacus* is moderately abundant here also.

The maximum thickness of the Aptian is about 600 feet in the southern part of the Lebanon mountains and the formation thins appreciably to the north, being reported as about 200 feet thick in its northern exposures. The overlying Albian strata, on the other hand, thicken to the north. In the latitude of Beirut there are about 250 feet of limestones, some sandy, and shales containing a fauna marked by *Heteraster delgadoi* and *Knemiceras*

syriacum, which are referred to this epoch. The basal zone is a massive, brown, sandy limestone containing abundant casts of large pelecypods, particularly a species of *Isocardia* (?). This bed, which commonly furnishes building stone for the mountain villagers, has long been known as the "*Cardium* Bank" and ranks with the "Failles de blanche" as a key horizon in stratigraphic studies.

The gray limestones of the Cenomanian closely resemble those of the upper Albian and it is often difficult to draw the line between the two horizons. Fossils are not widely distributed in this horizon, though, where present, they are apt to be exceedingly abundant and of varied types. Rudistid pelecypods flourished at this time, and species of *Nerinea* are particularly well developed, though they occur throughout the section. The most noticeable diagnostic feature of these Cenomanian strata is the occurrence of abundant large, whitish, siliceous concretions. Such concretions were not observed in the Albian deposits and, in mapping, it was found most practicable to draw the line between the two horizons at the base of the lowest concretionary limestone. As thus interpreted, the thickness of the Cenomanian is approximately 1,500 feet.

At Hakil and Hajula (Djula), the white shales of the Cenomanian carry a well-preserved and rich fauna of fossil fish. These localities, together with the Senonian deposits at Sahil Alma, have yielded the well-known fish faunas described by Pictet, O. P. Hay, and Smith Woodward. During the course of the present investigations, a small flora associated with fossil invertebrates and fish was obtained from Hajula. In so far as I am aware, it is the first identifiable flora to be found in the Lebanon.

The Cenomanian deposits are the highest Cretaceous strata present within the main mass of the Lebanons. Turonian and Senonian strata occur on the flanks, but there is no evidence that they ever were present over the entire region. In their most characteristic development, they consist of chalky white shales and limestones. Fossils are abundant at some localities, but are not disseminated throughout the formations.

Structurally, the Lebanon Mountains are an upfaulted horst, the fault on the western margin serving also to mark the eastern end of the Mediterranean Sea in that region. The eastern fault scarp marks the western side of the Bekaa, a long narrow fault valley, which has been interpreted as the northern end of the Jordan Rift Valley, and, possibly, of the great African Rift zone. In addition to these major fault zones, which bound the range, there is a prominent transverse fault zone running east-west from the region of Beirut at least as far as Jebel Kenaise (one of the high peaks on the eastern side of the range). To the north of this fault zone, the central part of the range is composed of upfaulted beds lying essentially horizontally, so that the Jurassic deposits outcrop along the lower elevations of the western part of the mountains, with the Cenomanian forming the high eastern peaks, including Jebel Kenaise, Jebel Sannine, and Jebel Mneitri. To the south of the fault zone, the high eastern peaks, particularly Jebel Baruk, are composed of the Jurassic rocks brought up between the eastern marginal fault and another longitudinal fault, which parallels it from a point north of Ain Zahalta to the southern margin of the region studied. There is a general uplift of the strata along the western side of this parallel fault and the Cretaceous strata have a general regional dip to the west, away from the uplifted Jurassic deposits.

In general, the structural complications presented by the longitudinal fault marking the eastern margin of the Lebanons are much more simple than those to be found along the western margin of the range, where the marginal fault line is a complicated zone that has greatly disturbed the entire marginal belt of strata. Vertical dips are common and the relatively greater degree of cultivation and terracing here has reduced the number of outcrops in critical areas. Considerable field-work is necessary before all the facts required for a critical discussion of this area can be assembled.

It was essential that I return to New York by the first of November. With Italy in the war, the Mediterranean was closed, and the logical road home was eastward. Two routes were avail-

able. An air-conditioned bus-line runs from Damascus to Bagdad, and an uncertain railroad goes from there to Bassra, where an occasional boat could be taken to Bombay. I chose rather to go to Jerusalem, from whence the Dutch KLM airline maintains a weekly service via Bagdad, Bassra, Karachi, Calcutta, Rangoon, Bankok and Penang to Singapore and Batavia. I found no difficulty in arranging for passage from Jerusalem to Singapore, and from thence to the United States.

ROBERT E. MARSHAK, University of Rochester and HANS A. BETHE, Cornell University: *The Sources of Stellar Energy* (A. Cressy Morrison Astronomical Prize Winner, 1940).[1]

PART I

The energy production in stars of the main sequence may be quantitatively accounted for by means of the carbon cycle of nuclear reactions suggested by Professor Hans A. Bethe two years ago. This applies even to the red dwarfs with the need of introducing the proton-proton reaction, whose importance is uncertain.

PART II

The distribution of density pressure and temperature within the white dwarf stars has been calculated by mechanical integration. The whole mass except for a thin outer shell is in the degenerate state. The central temperature of the companion of Sirius comes out 15 million degrees and that of the companion of o^2 Eridani, 30 million degrees. The energy supplies of these stars must be derived, not from nuclear reactions, but from gravitational contacts which could supply their radiation for hundreds of millions of years in the future.

[1] Abstracted by Professor Henry Norris Russell, Princeton University.

PRESTON E. CLOUD, Missouri School of Mines and Metallurgy:
Terebratuloid Brachiopods of the Silurian and Devonian.
(A. Cressy Morrison Prize Winner, 1940.)[1]

This paper comprises the results of a critical restudy of the Silurian and Devonian terebratuloids, based on the collections at Yale and the U. S. National Museum and supplemented by borrowed material. The morphology, stratigraphic range, geographic distribution, and evolutionary possibilities of the group are discussed and a classification is proposed. It is suggested that the Dalmanellacea may have been the ancestors of the terebratuloids.

It is shown that, contrary to previous opinion, the earliest known terebratuloids appeared in late rather than early Silurian time. The genus *Brotozeuga*, on which the earlier age was based, is now known to be a spire-bearer, related to *Dayia*, and the family Protozeugae is invalidated.

The validity of the 42 published generic names, including those said to be synonyms and homonyms, was independently reinvestigated. As a result 23 of the names are recognized as valid, 1 as doubtful but uncertain validity, 1 as of uncertain position, 7 as objective synonyms, 5 as subjective synonyms, 2 as homonyms, and 3 as non-terebratuloid genera. It is pointed out that 3 other names are non-generic group terms. In addition 8 new genera are proposed, making a total of 31 believed to be valid.

The 31 genera are grouped in 5 families of which 1 is new, and 13 subfamilies of which 10 are new. The relatively large number of subfamilies was necessary because of the great variability of the early terebratuloids and the fact that some of them include post-Devonian genera.

Every species, of which I could learn, was briefly studied from specimens or from the literature, and most of the approximately 250 are assigned to or provisionally listed under some known genus. Nine new species are names. By clearing the old genera of misplaced species, their stratigraphic ranges were more closely established and the new genera discovered.

[1] Abstracted by the author.

By means of various techniques, the brachidia were determined for the majority of the genera, the hitherto unknown loops of *Amphigenia* and of the genotype species of *Rensselandia* being among them. The loops of 4 of the 8 new genera are made known, and additional details are added to the knowledge of the brachial structures of other genera. It was found that the loop was subject to considerable individual variation and is of little value for classification other than in a general way.

In the classification, the structures in the posterior of the dorsal valve were found to be of prime importance. In general, families are based chiefly on major structural differences in the cardinalia; subfamilies on features of the ventral interior and beak region, as well as on differences in the cardinalia; and genera, on persistent structural variations in either valve, and major external differences. Where the impressions of the muscles and pallial sinuses are clear and where characters of the loop are sufficiently stable, they are used as supplementary criteria. For specific characters, there remain minor variations in external and internal morphology and, in some genera, variations in density of punctation.

C. F. DEGARIS, University of Oklahoma School of Medicine: *The Aortic Arch in Primates.* (A. Cressy Morrison Prize Winner, 1940.)[1]

Materials of this report comprise aortic arches distributed thus: among Lemuroidea from our collection, 10 specimens; from the literature 11 specimens; among Anthropoidea from our collection, 409 specimens (268 of *Pithecus rhesus*); from the literature, 58 specimens; total, 488 specimens, with over 50 species, each subfamily being represented. Higher primates in our collection are 7 gibbons, 14 orang-utans, 22 chimpanzees, 1 gorilla. Aortic patterns are given letter-symbols thus: A = usual human sequence aortic branches; B = common root for left carotid and anonyma; C = common trunk for same; elongated C patterns

[1] Abstracted by the author.

are designated C^1, C^2, C^3, etc.; F = a. thyreoidea ima; H = bi-innominate. Excluding Tarsiiformes and Platyrrhinae, aortic patterns grade from very long C of Lorisformes and Lemuriformes, through long to short C of Catarrhinae, to A in chimpanzee, gorilla and man. Tarsiers and most platyrhines have patterns (A), inappropriate to their positions in the classification. Such patterns and many other morphological characters bespeak early genetic independence of these animals from the main primate line. The same holds for higher primates, including man. Diverse aortic patterns may reflect more general physical differences. The relations of aortic patterns to cephalic thoracic outlet and to level of aortic arch are discussed. Complete findings according to species in our collection and from the literature are interpolated in Elliot's classification of the Order Primates. In aortic patterns, direction of aortic variants and thoracic index, the chimpanzee stands statistically in closer relation to man than do any other primates.

SECTION OF PHYSICS AND CHEMISTRY

NOVEMBER 8 and 9, 1940

Conference on "*The Amphoteric Properties of Proteins*"

The Section of Physics and Chemistry held a Conference on "The Amphoteric Properties of Proteins," the first of the series this year. Doctor R. Keith Cannan, New York University, College of Medicine, was in charge of this meeting as Conference Chairman.

The program consisted of the following papers:

"The Amphoteric Properties of Egg Albumin," by Doctors R. Keith Cannan, A. Kibrick and A. H. Palmer, New York University, College of Medicine.

"The Influence of pH on the Mobility and Diffusion of Egg Albumin," by Doctor L. G. Longsworth, Rockefeller Institute for Medical Research.

"Participation of Anions in the Combination of Acids with Proteins," by Doctor Jacinto Steinhardt, National Bureau of Standards.

"The Acid-base Equilibrium of Ampholytes," by Doctor J. G. Kirkwood, Cornell University.

It is planned to hold two additional conferences in this series, announcements of which will be made later.

NEW MEMBERS

Elected December, 1940

LIFE MEMBER

Burdick, C. Lalor, Ph.D., Assistant to the President, E. I. du Pont de Nemours & Co., Wilmington, Del.

SUSTAINING MEMBER

Escalon, Salvador, LL.D. (Paris), Salvador, Central America.

ACTIVE MEMBERS

Allen, John Carlin, B.S., President, Technigraph, Inc., New York, N. Y.

Chow, Bacon Field, Ph.D., Research Associate, Chemistry, Squibb Institute for Medical Research, New Brunswick, N. J.

Daniel, Janet, Ph.D., Research Associate, Chemistry, Columbia University, New York, N. Y.

Edwards, Roy T., Ph.D., Chemist, Socony-Vacuum Oil Co., New York, N. Y.

Hamer, Walter J., Ph.D., Associate Chemist, National Bureau of Standards, Washington, D. C.

Hicks, Victor, Ph.D., Physicist, Westinghouse X-ray Co., Inc., Long Island City, N. Y.

Hutt, Max L., M.S., Head, Educational Clinic, The College of the City of New York, New York, N. Y.

Kennedy, Lou, Ph.D., Associate Professor, Speech, Brooklyn College, Brooklyn, N. Y.

Kornfeld, Gertrude, Ph.D. (Prague), Physical Chemistry, Member, Eastman Research Laboratories, Rochester, N. Y.

Lauzer, Edward S., M.D., Biology, Anthropology, Rock Springs, Wyo.

Mayer, Joseph E., Ph.D., Associate Professor, Chemistry, Columbia University, New York, N. Y.

Muncie, Wendell, M.D., Associate Professor, Psychiatry, Johns Hopkins University Medical School, Baltimore, Md.

Murphy, William Parry, M.D., Senior Associate, Medicine, Peter Bent Brigham Hospital, Boston, Mass.

Murray, Robert T. K., Ph.D., Instructor, Physics, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Nabrit, Samuel Milton, Ph.D., Professor, Biology, Atlanta University, Atlanta, Ga.

Neilson, Preston M., LL.B., Lawyer, New York, N. Y.

Nielsen, Walter M., Ph.D., Professor, Physics, Duke University, Durham, N. C.

Noble, Ralph E., B.S., Junior Bacteriologist, U. S. Public Health Service, Chicago, Ill.

Nord, Friedrich Franz, Sc.D., Professor, Chemistry, Fordham University, Bronx, N. Y.
Noyes, Helen Miller, M.A., Chemistry, Carthage, Ill.
Paine, Harold W., Ph.B., B.Sc., Chemical Director, Plastics Department, E. I. du Pont de Nemours & Co., Arlington, N. J.
Parsons, Louis A., Ph.D., Professor Emeritus, Physics, Witman College, Walla Walla, Wash.
Powell, Horace M., Sc.D., Bacteriologist, Eli Lilly & Co., Indianapolis, Ind.
Rogers, Spaulding, B.A., Graduate Assistant, Psychology, Columbia University, New York, N. Y.
Shlaer, Simon, Ph.D., Research Assistant, Laboratory of Biophysics, Columbia University, New York, N. Y.
Strain, William S., M.S., Curator, Museum, Texas College of Mines and Metallurgy, El Paso, Texas.
Valentine, Wilbur G., Ph.D., Instructor, Geology, Brooklyn College, Brooklyn, N. Y.
Vance, John E., Ph.D., Assistant Professor, Sterling Chemistry Laboratory, Yale University, New Haven, Conn.
Wagner, Loretta A., Ph.D., Instructor, Speech, Brooklyn College, Brooklyn, N. Y.
Weber, Margaretta, M.A., Psychologist, Bureau of Reference, Research and Statistics, Board of Education, New York, N. Y.
Wiley, Robert, Biochemistry, U. S. Army, Corps Area Laboratory, Brooklyn, N. Y.
Zim, Herbert S., Ph.D., Head, Science, Ethical Culture Schools, New York, N. Y.

ASSOCIATE MEMBERS

Bott, Phyllis A., Ph.D., Research Associate, Pharmacology, University of Pennsylvania, Philadelphia, Pa.
Carr, Emma Perry, Ph.D., D.Sc., Professor, Chairman, Chemistry, Mount Holyoke College, South Hadley, Mass.
Dushman, Saul, Ph.D., Assistant Director, Physical Chemistry, Research Laboratories, General Electric Co., Schenectady, N. Y.
Hart, Edwin J., Ph.D., Chemistry, U. S. Rubber Co., Passaic, N. J.
Howe, John P., Ph.D., Assistant Professor, Chemistry, Brown University, Providence, R. I.
Jackson, Richard W., Ph.D., Chief, Protein Division, Eastern Regional Laboratory, Chestnut Hill, Philadelphia, Pa.
Laidler, Keith James, Ph.D., Research Chemist, National Research Council of Canada, Ottawa, Ontario, Canada.
Matheson, Max S., Ph.D., Research Chemist, U. S. Rubber Co., Passaic, N. J.
Nadeau, Gale F., Ph.D., Supervisor, Film Base Dept., Eastman Kodak Co., Rochester, N. Y.
Nagge, Joseph William, Ph.D., Associate Professor, Psychology, Kansas State Teachers College of Emporia, Emporia, Kansas.
Nicholson, Fredric M., M.D., Ph.D., Physician & Surgeon, Chicago, Ill.
Poindexter, Hildrus A., M.D., Ph.D., Professor, Head, Bacteriology, Howard University, College of Medicine, Washington, D. C.

Potter, Truman S., M.D., Research Associate, Preventive Medicine, University of Chicago, Chicago, Ill.

Prescott, Gerald W., Ph.D., Associate Professor, Biology, Albion College, Albion, Mich.

Sprince, Herbert, Ph.D., Research Associate, Biochemistry, Cornell University, College of Medicine, New York, N. Y.

STUDENT MEMBERS

Frick, Frederick C., B.A., Graduate Student, Psychology, Columbia University, New York, N. Y.

Walovnick, Sidney, Geology, Student, College of the City of New York, New York, N. Y.